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'FUSED-ON' ROTATING BANDS FOR PROJECTILES

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Philadelphia, Pennsylvania

December 1974

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The purpose of this work was to determine the feasibility of a new idea for applying rotating bands to projectiles. The idea is the in-situ fusion of the rotating band material in a graphite crucible fitted around the projectile. Various heating and shielding methods were explored. It was found that several materials could be successfully deposited using induction or furnace heating in an Argon atmosphere. Metallographic studies (cont.)

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20. Abstract (cont.)

and post-application, heat treating studies were carried out. Several bands "fused on" 30 mm projectiles were successfully fired through a 30 mm cannon.

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INTRODUCTION

This project was established to determine the feasibility of an in-situ fusion method of applying rotating bands to projectiles. This new in-situ concept (otherwise called Fused On Band) involves in-place melting and solidification of the band material, thus producing wetting and bonding of the material to the projectile wall.

The work consisted of experiments with several band materials and heating methods. Metallographic examinations were conducted on banded projectiles to determine the effects of the banding operation and subsequent heat treatment on the projectile's steel wall. In addition, a small scale firing test was conducted which demonstrated the effective functioning of projectiles banded by this method.

Traditionally, projectiles have been banded by swaging a ring of soft metal into a knurled and undercut groove which is cut into the projectile wall. One of the disadvantages of a band of this type is that it is liable, under certain circumstances, to be thrown from the projectile in firing. Thrown bands are undesirable because of the danger to friendly troops and equipment.

Additional disadvantages accrue to this type of band as attempts are made to design more modern projectiles with thinner walls, higher explosive to weight ratios, and higher velocities. In such design work, difficulty is encountered in achieving the design objective because of the necessity for the projectile to withstand the large forces incident to swaging of the band. Thus, a web or a thickened wall must be used at the band position inside the projectile to provide sufficient strength. Also, as higher velocities are sought, swaged bands tend to become more prone to malfunction.

Because of these various disadvantages of the swaged band, the more recently invented welded overlay rotating band has found favor for new generations of artillery projectiles. In this method of banding projectiles, a welded overlay is deposited on the outside of the projectile by the gas-metal arc-welding process. The overlay is bonded to the projectile wall and cannot come off if deposited correctly. Shallow band seats may be used if desired or the deposit can be applied to a perfectly straight wall. Various materials have been deposited in this way, including copper, gilding metal, aluminum bronzes and iron. After the overlay is deposited it is machined to band configuration by conventional machining techniques. Projectiles from 20 mm to 280 mm in diameter have been banded by this method.

Overlay banding also has certain disadvantages, however. Among these are that it is too slow at the current state-of-the-art to be a practical production method for banding small conventional projectiles. An additional disadvantage lies in the fact that the nonferrous overlay materials penetrate the austenitic grain boundaries of the steel shell being overlayed, thus introducing minute flaws into the wall of the shell being banded. These have demonstrable negative effects on shell wall strength and can introduce quench cracks in heat treating operations. The "fused on" band idea, therefore, was conceived in view of the desirability of producing an overlay type of band without some of its less desirable characteristics. In considering the new method, it appeared that the resulting band would be fully comparable with the overlay in terms of its strong bond and thus its applicability to thin walled shell. In addition to this similarity, however, the new method could have advantages over the overlay in that a greater savings in copper would be likely because of the ability to produce a configuration conforming more closely to the final band shape and dimensions. This would reduce scrap losses.

Also much higher application speeds seemed possible particularly with respect to small caliber projectiles if automated induction facilities or large furnaces could be suitably applied. A most significant possibility would be an improvement over the overlay process with respect to intergranular penetration. It was believed that the latter advantage could be expected because in the "fused on" band process the shell is heated all the way through, rather than just at the surface, as in the welding process. The significance of this difference is the fact that ferrous materials undergo a volume decrease due to lattice changes when heated into the austenitic range of temperature.

When the shell is heated all the way through, this simply results in a decrease in the volume occupied by the steel or, in effect, a density increase. However, if the heat affected zone does not penetrate the wall, a stress is established between the transformed and untransformed regions because of the volume differential. It is believed that this tensile stress exacerbates the problems of grain boundary penetration and cracking in the overlay process and that the occurrence of tensile stress would be precluded by the nature of the "fused on" band process.

This report describes experimentation with the new method and the results obtained from the experimentation.

MATERIALS AND EQUIPMENT

Equipment employed in the experimentation described herein consisted mainly of a 20 kilowatt high frequency electronic tube type induction heater, and a tube furnace capable of temperatures in excess of 2000° F, with a three inch, stainless steel muffle and readily accessible fittings for adaptation to bottled gases. Standard metallographic facilities were employed for the metallography.

Materials used consisted of 30 mm projectile bodies made of 4145 steel and the following materials in the form of shot made by cutting up welding wires:

Copper Development Association Alloy No. 189

Nominal Composition

98.75 Cu
0.75 Sn
0.3 Si
0.20 Mn

Copper Development Association Alloy No. 240 (Low Brass)

Nominal Composition

80.0 Cu
20.0 Zn

Copper Development Association Alloy No. 524 (Phosphor Bronze)

Nominal Composition

90.0 Cu
10.0 Sn
Trace P

The copper alloys cited above were not necessarily considered optimum materials for rotating bands or the process described in this report. They were used simply because they were readily available and are similar to materials presently used for rotating bands. Other compositions, particularly amongst the copper casting alloys, might be preferable for the process or as rotating band materials depending on projectile requirements.

METHODS AND PROCEDURES

In this in-situ method of banding projectiles, a mold of graphite is prepared which fits closely around the bottom of the projectile. The mold has an appropriately sized cavity in the position where the band is desired. A refractory wash of zirconia flour is applied to the mold to prevent diffusion of carbon or other undesirable elements into the steel shell wall. The shell is then put into position and shot of the desired band composition is poured into the mold cavity. Figure 1 illustrates this arrangement. It is anticipated that a preform of the band material would perhaps be more satisfactory than shot, but in the experimental work, accomplished thus far, shot has been used because of the availability of the wire and the expense of machining preforms. However, in production, preforms could be made inexpensively using tubing cutoffs or some other easily formed blanks.

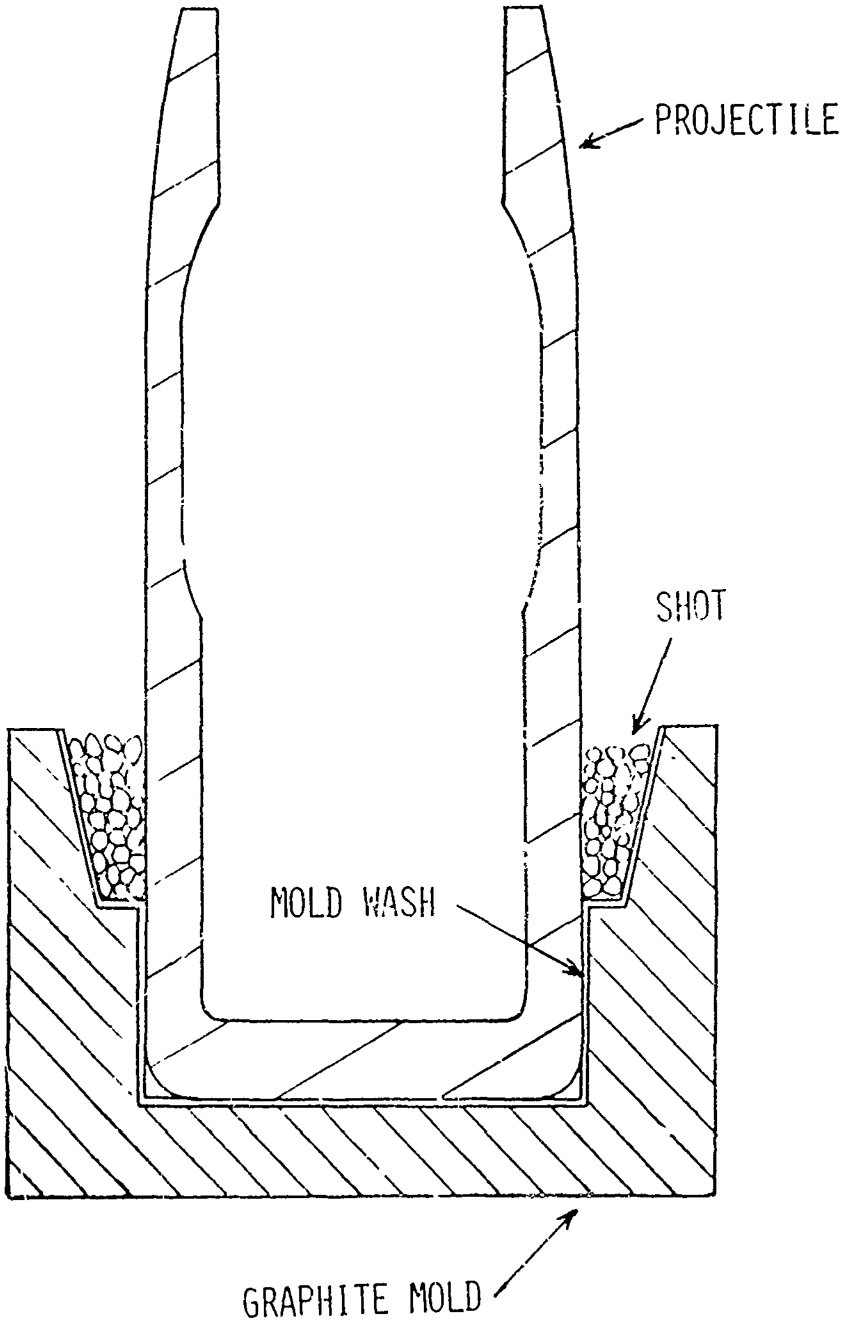


Figure 1. Schematic Showing Projectile Body, Mold and Shot Assembly Preparatory to Banding Operation

After the band material is added to the mold the entire assembly is heated in a non-oxidizing environment until the band alloy melts and bonds to the steel shell wall. Figure 2 shows a deposit being applied in an induction coil under an argon cover. The graphite mold shown provides a good susceptor for induction heating. Induction heating was employed almost exclusively in early experimentation although some initial experimentation was also done with furnace heating methods.

Another major variable in the experiments was band composition. Materials experimented with were as described in the Materials and Equipment section of this report.

Shielding of the process is required to protect the graphite mold for reuse and avoid oxidation of the projectile wall which would otherwise prevent wetting of the steel. This too has been the subject of some of the experimentation performed thus far. Argon, proved to be a suitable shielding gas and was used throughout the work reported here.

When techniques of application were developed to the extent that suitable looking bands were formed, heat treating experiments were performed along with metallographic examinations to determine the quality of the deposit and whether undesirable structures produced in the steel body wall by the banding operation could be rectified by subsequent heat treatment.

In addition, a small scale firing test was conducted to determine if the applied bands would perform satisfactorily.

RESULTS AND DISCUSSION

Successful Experiments

Figure 3 shows three raw band deposits that were applied to 30 mm projectiles under argon cover by induction heating. From left to right the bands are Copper Development Association Alloy 189, low brass, and phosphor bronze. After experimentation had reached the point where deposits of the quality shown in Figure 3 could be produced with regularity, specimens were metallographically examined to observe the interface, soundness of deposit and the effects of the process on the underlying steel.

Figure 4 shows a macrograph of a cross section of an induction fused copper (Alloy 189) band deposit. This shows that in wetting the steel, the alloy readily climbed the body wall forming a natural contact angle at the top of the band deposit. The quality of the band on a macroscale appears sound and the general configuration of the deposit is obvious.

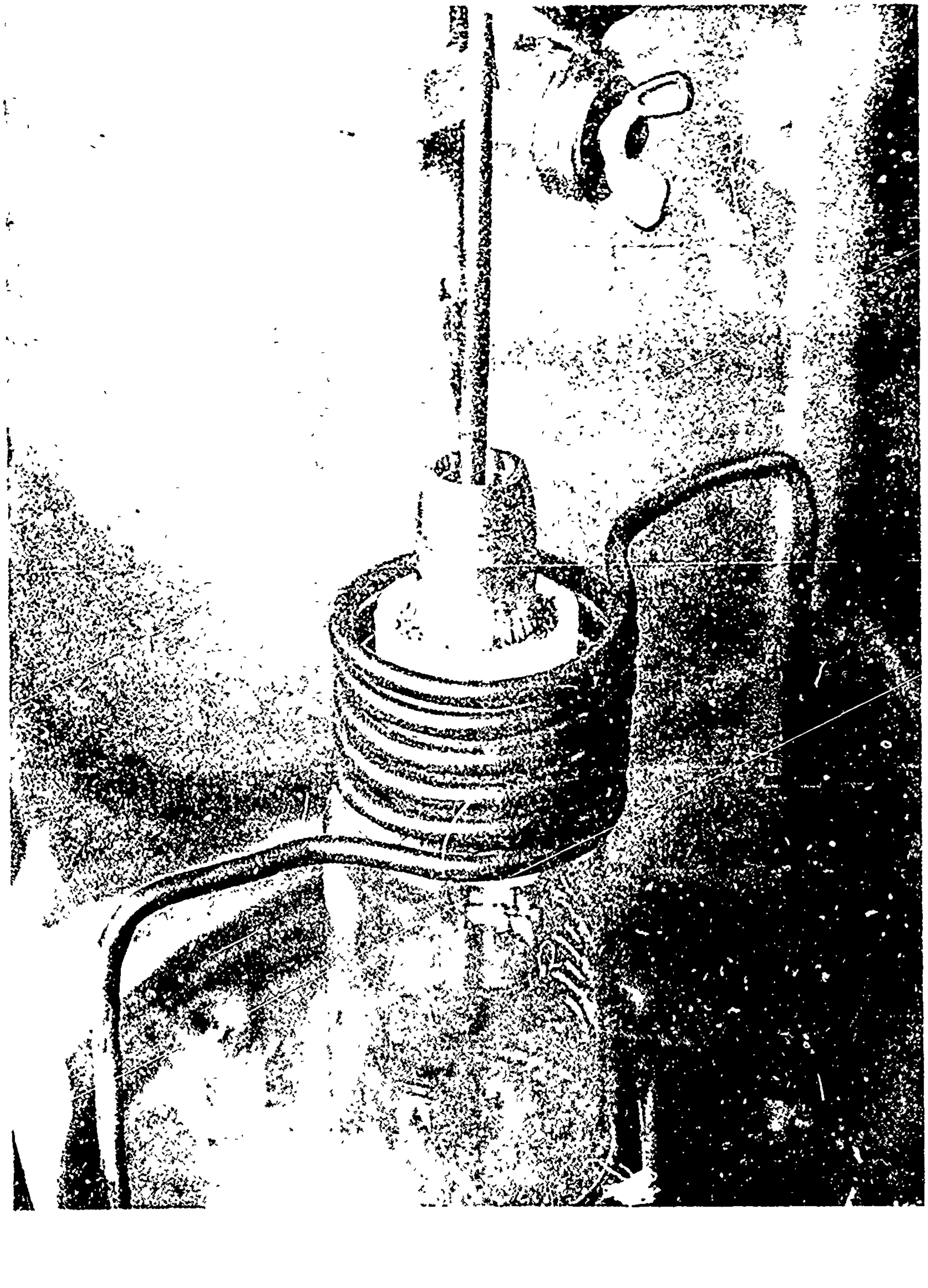


Figure 2. Induction Heating of Mold, Shot, and Projectile Body Within Argon Filled Bell Jar

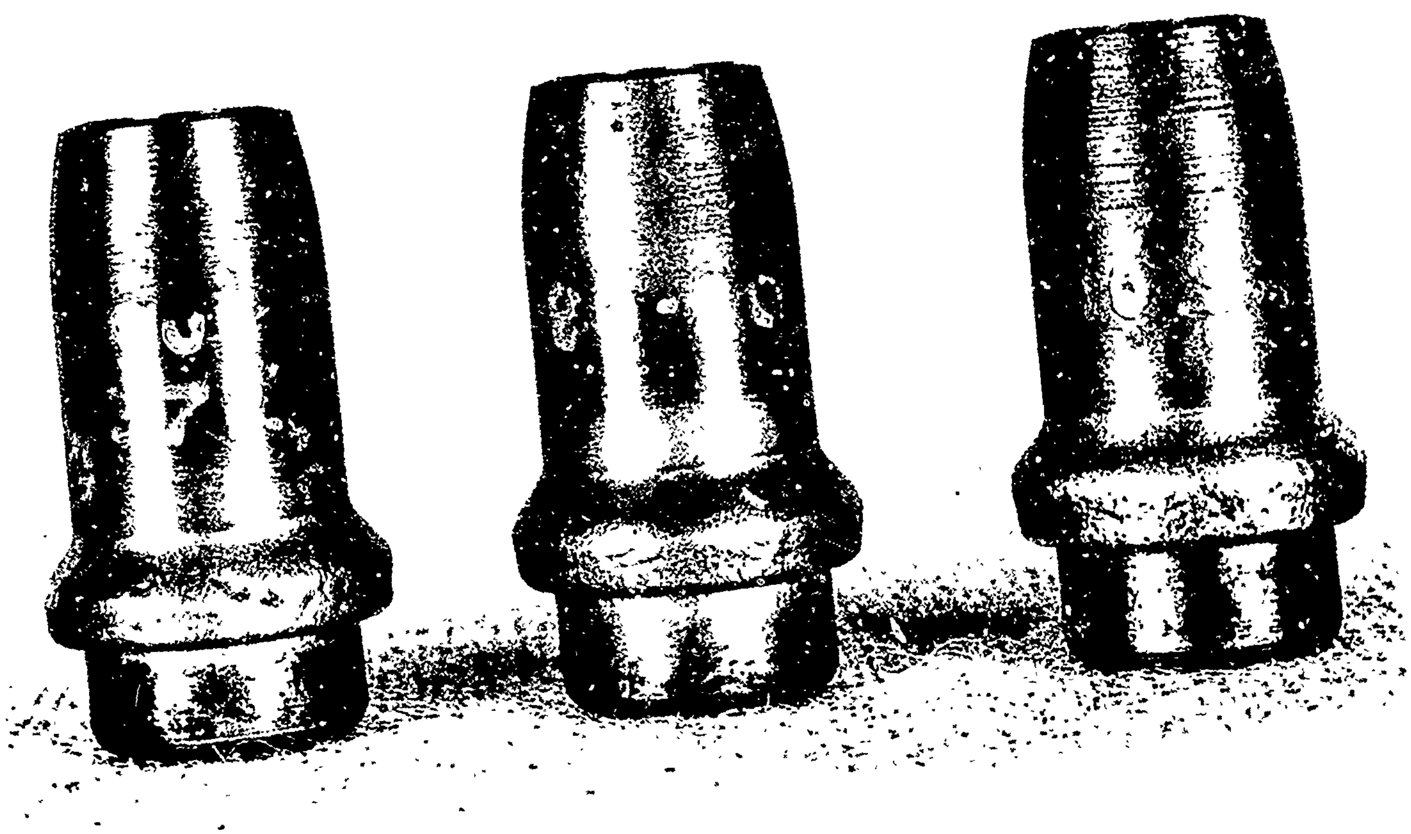
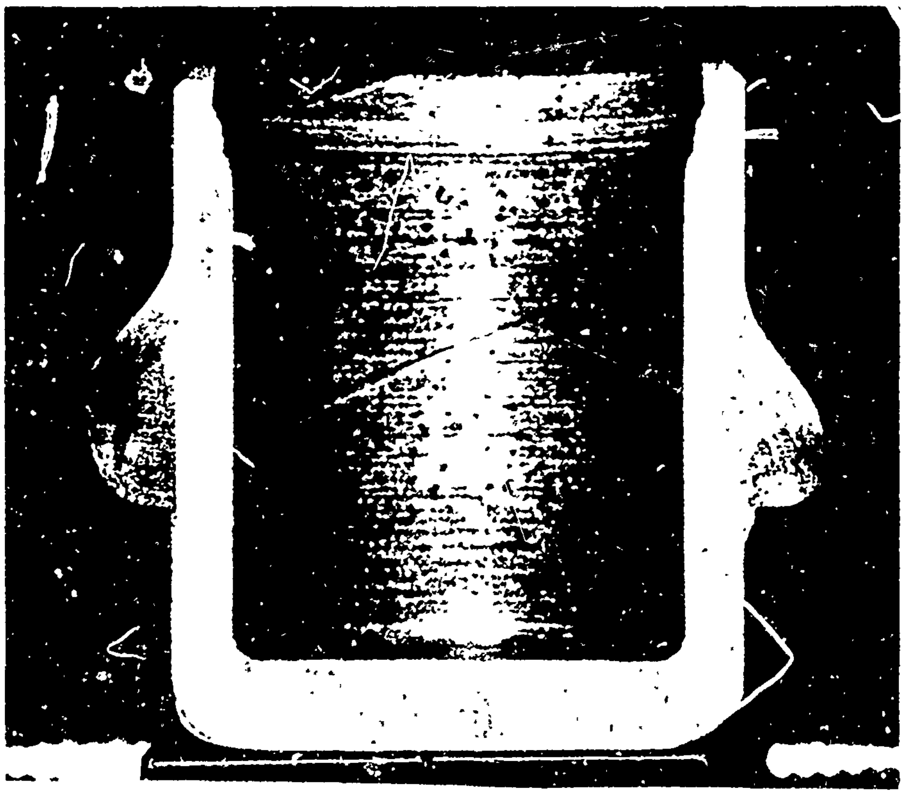


Figure 3. Induction Fused Band Deposits, Left to Right: Cu Alloy 189 Low Brass and Phosphor Bronze



Etch: Steel; Nital Cu; NH_4OH, H_2O_2

Mag: 2-1/2 X

Figure 4. Section From 4145 Steel 30 mm Projectile Body Showing Induction Fused Copper (Alloy 189) Band

The photomicrograph, Figure 5, shows at 100 magnifications, the interface produced between the 4145 steel projectile wall and the copper deposit. It may be seen that an excellent bond has been achieved. There is slight intergranular penetration of the prior austenitic grain boundaries, some decarburization at the steel surface and quite large grains (about ASTM 3) immediately below the deposit. The largeness of the grains is the result of grain growth which occurred at the high temperatures (approximately 2000 degrees) incurred in the banding process. The degree of grain growth and decarburization can be appreciated by observing Figure 6 which shows the metallographic structure of the projectile wall in the as-received condition.

Figure 7 shows a typical intergranular intrusion and also the nature of the bond at higher magnification than in Figure 5. It may be seen that the bond still appears excellent at this magnification and that the intergranular intrusion is approximately 0.0005 inch in depth. This is considerably less than is usually found in welded overlay deposits.

Figure 8 shows the microstructure at the interface and in the shell wall after austenitizing 30 minutes at 1500° F, quenching in oil and tempering for one hour at 1000° F. This is a typical heat treatment for this steel. It may be seen that grain size at the interface has been greatly refined and is the same as that found in the rest of the projectile wall. The grain size is now about ASTM 8, which is quite fine. In addition the area has been recarburized by diffusion of carbon into the decarburized area. Thus it appears that if subsequent heat treatments are employed, there are no undesirable, irreversible metallurgical effects on the steel which occur as a result of the banding operation.

Good bonding is also obtained at the interfaces with low brass and phosphor bronze "fused on" bands. Figure 9 shows the interface obtained with an induction fused, low brass, deposit. It can be seen that there is some intergranular penetration. Excellent wetting has been achieved and there is no decarburization as occurs with copper (Alloy 189). Figure 10 shows the interface obtained with an induction fused phosphor bronze deposit. This also shows little or no decarburization, good wetting and little intergranular penetration.

Thus far the effects of banding by this method have been illustrated mostly on a microscale at considerable magnification. It was also useful to examine the projectile wall on a macroscale. Figures 11 and 12 illustrate 30 mm shells which had been equipped respectively with "fused on" and welded rotating bands of copper (Alloy 189). The band deposits have been removed from the projectiles without attacking the steel by selective etching procedures. By comparing Figures 11 and 12, it can be seen that the welded overlay technique produces pitting of the steel wall whereas negligible wall damage is encountered with the "fused on" band.

Etch: Picral Mag: 100 X

Figure 5. Interface and Microstructure in 4145 Steel Substrate; As-Deposited Copper (Alloy 189)

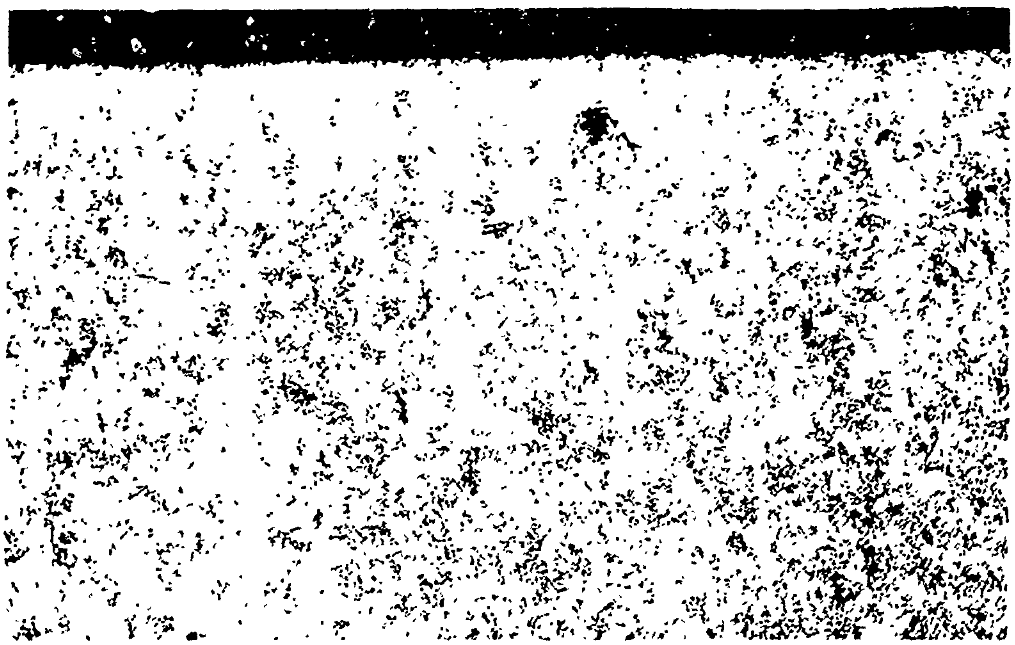


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Figure 6. Microstructure of 4145 Steel Wall of 30 mm Projectile Body As-Received

Etch: Picral Mag: 1000 X

Figure 7. Intergranular Intrusion of Copper (Alloy 189) Into 4145 Steel Grain Boundary; Induction Fused Band

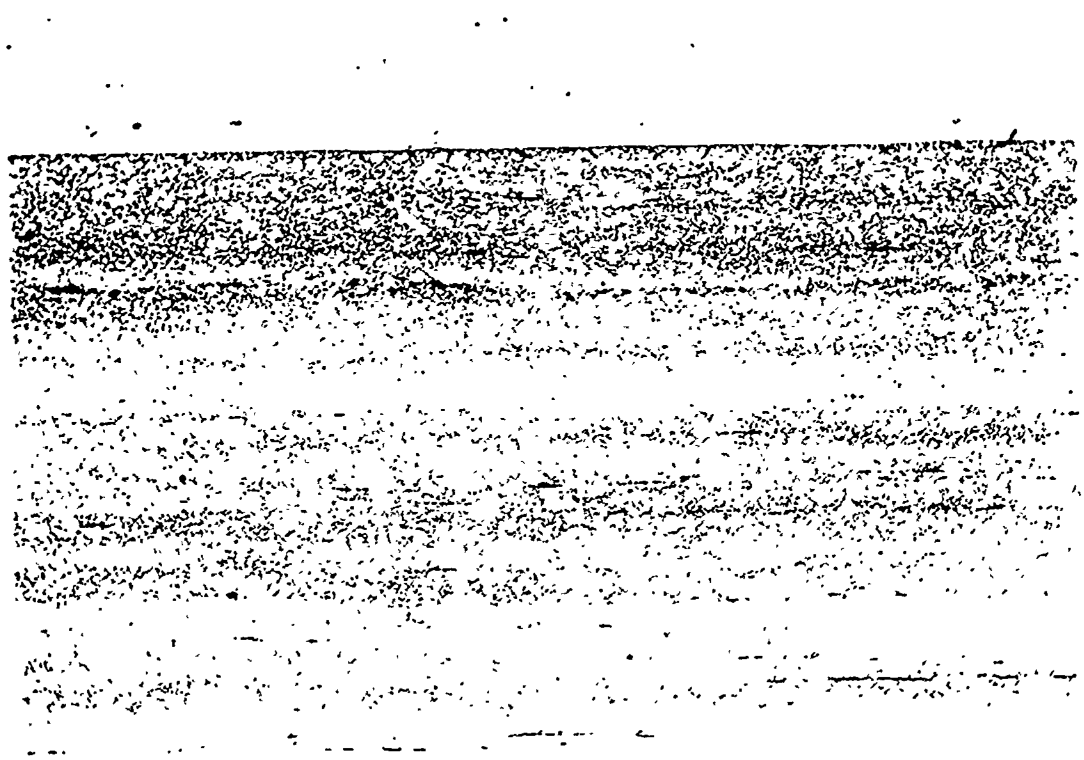

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Figure 8. Interface and Microstructure in 4145 Steel Substrate After Heat Treatment; Copper (Alloy 189) Deposit

Etch: Picral

Mag: 1000 X

Figure 9. Interface and Microstructure in 4145 Steel; As-Deposited Low Brass

Etch: Picral

Mag: 1000 X

Figure 10. Interface and Microstructure in 4145 Steel; As-Deposited Phosphor Bronze

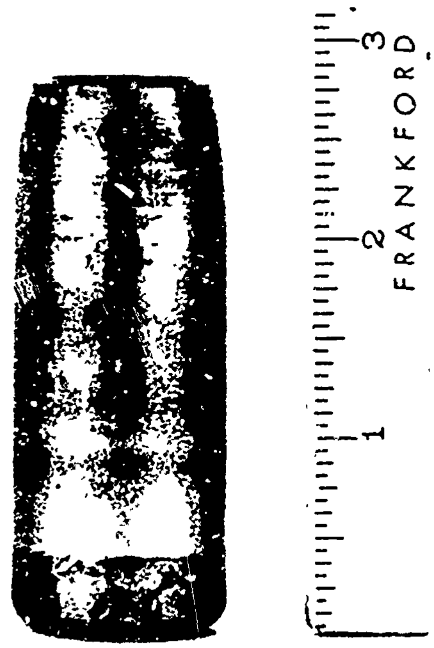


Figure 11. "Fused Cn" Band Removed by Selective Etching

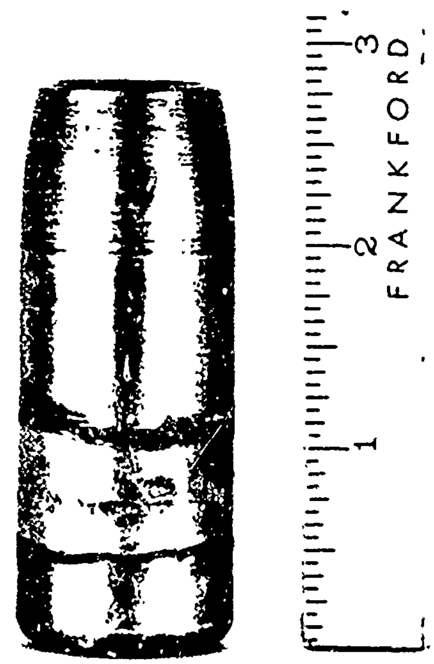


Figure 12. Welded Overlay Band Removed by Selective Etching

In preceding portions of this report it was pointed out that deposits were also applied to the projectiles using furnace methods. Figures 13 and 14 show, respectively, a copper (189 Alloy) furnace deposit and a cross section of such a deposit. While the deposit appears somewhat rough on the exterior due to external shrinkage defects, the cross section shows that the deposit is sound and could be successfully machined into a rotating band.

Figure 15 shows the interface between the 4145 steel projectile and a (189 Alloy) deposit. Again it can be seen that the bond is excellent but intergranular penetration is more severe than in the previously illustrated induction fused bands. To illustrate this condition a little better, Figure 16 shows a photomicrograph taken right at the bottom of the furnace deposited band blank. Here the amount of erosion can be seen and it would appear that right at this location about 0.010 inch of the steel has actually dissolved into the band deposit. This is believed due primarily to excessive time in the furnace. (The specimen was put in for one hour with the furnace set at 2050° F). Shorter times would probably reduce this erosion. However, the preliminary nature of this project did not permit adequate experimentation to determine appropriate furnace times.

For any given projectile or band material, this determination would probably require some degree of experimentation so that the assembly is not in the furnace any longer then is required to melt the band material. In the induction process, of course, it is possible to determine this by direct observation and erosion does not occur to any significant degree.

Having successfully demonstrated that deposits suitable for machining into rotating bands could be applied by this method it was decided to conduct a small scale firing test to verify whether or not the deposits would successfully function as rotating bands. Accordingly, several copper (Alloy 189) induction fused bands were applied to 30 mm HEI T306 E10 projectile bodies. The bodies were then heat treated and the deposits and bodies were machined to the configuration shown in Figure 17.

Three projectiles were fired at velocities between 2800 and 3000 feet per second. The results of these tests are illustrated in Figure 18. The two projectiles on the left were fired at chamber pressures of 70,000 pounds per square inch. The projectile on the right was fired at a chamber pressure of 90,000 pounds per square inch. It may be seen that the bands performed well. Of particular noteworthiness is the fact that even on the projectile which has fractured on impact (left projectile) all parts of the band have remained attached to the steel.

Problem Areas

One of the problems encountered in banding the projectiles, particularly in the early stages of experimentation, was that the banding

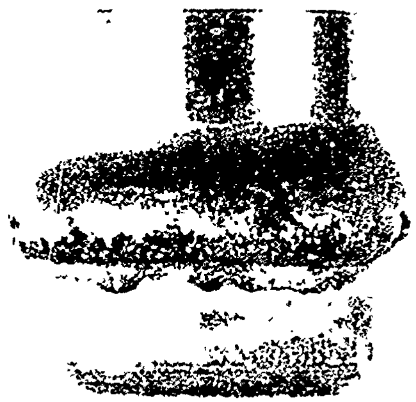


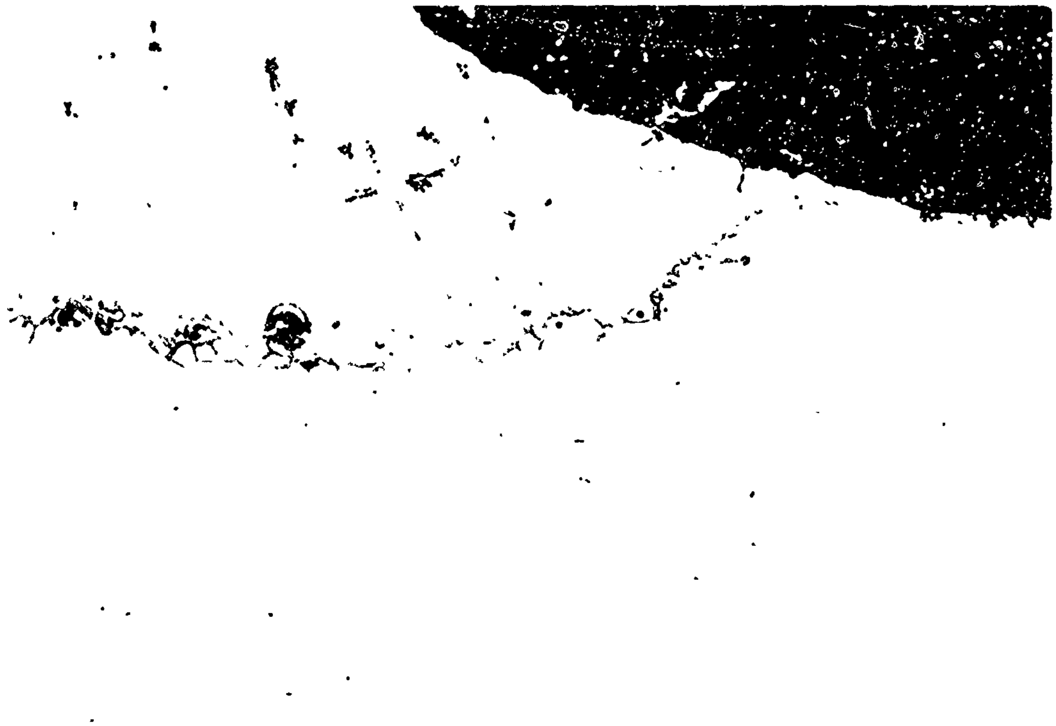
Figure 13. "Fused On" Band Deposit Made in Furnace with Argon Atmosphere; Copper (Alloy 189)

Figure 14. Cross Section of Fused on Band Deposit Made in Furnace with Argon Atmosphere; Copper (Alloy 189)

Etch: Picral

Mag· 100 X

Figure 15. Interface and Microstructure in 4145 Steel; Furnace Deposited Copper (Alloy 189); As-Deposited Condition



Etch: None

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Figure 16. Erosion of 4145 Steel Shell Wall at Base of Furnace Deposit

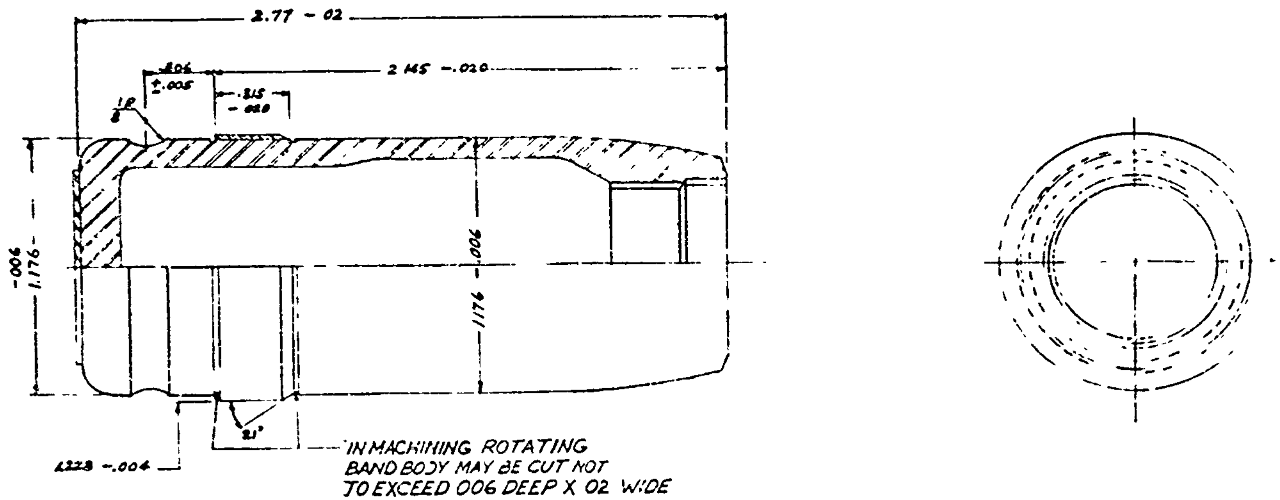

Figure 17. 30 mm HEI T306 E10 Projectile Equipped with Fused On Band

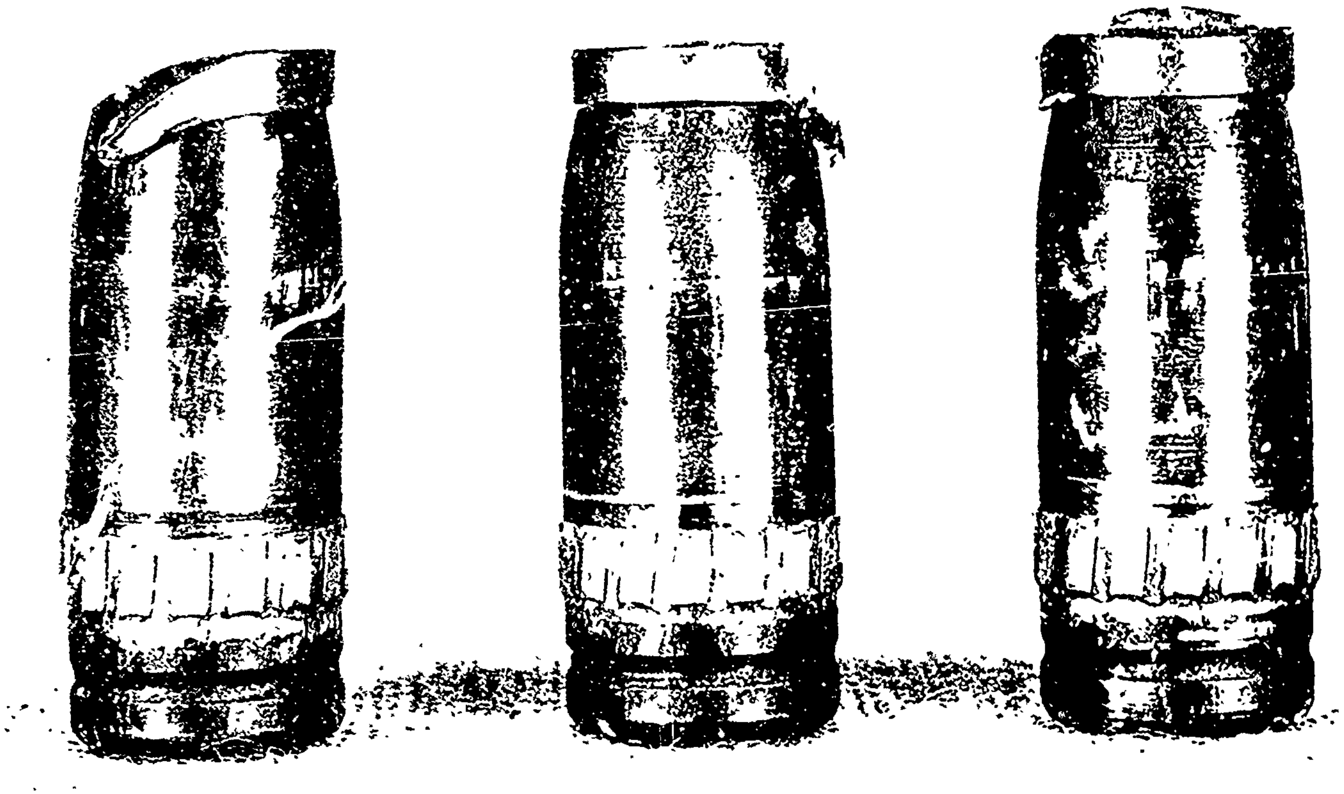

Figure 18. Fired 30 mm HEI T306 E10 Projectiles Equipped with Induction Fused, Copper (Alloy 189) Bands

material upon wetting the steel body would sometimes run down onto the bottom of the projectile. This was successfully corrected by decreasing the clearance between the shell and the mold wall so that after the application of the mold wash slight pressure was required to seat the projectile into the mold.

Another problem found with induction heating was that in some instances slight pitting was encountered in the bottom of the shell. It was not possible to determine with certainty the cause of this but it was speculated that it was either the result of local diffusion of carbon into the shell thus lowering its melting point or else was caused by arcing between the shell wall and the mold. The latter cause was thought most probable because this problem did not occur in furnace banding.

In any event it is believed that both of the above problems might be overcome by adjustments in the banding methods or perhaps better still, by altering the sequence of operations in producing a given projectile. More specifically stated, the band deposit could be applied in very early stages of the projectile manufacture, perhaps to a rough bored piece of bar stock with only the band position machined to projectile bourrelet diameter. All finish machining operations would be done after the band deposit was applied.

Another problem that was encountered was occasional unsoundness in phosphor bronze band deposits due to shrinkage defects. This problem is illustrated by Figure 19. Some of the copper casting alloys, if satisfactory as band materials, might also prove to be much more satisfactory in providing sound deposits.

Experimental Failures

Experiments which attained a reasonable degree of success have been emphasized thus far in this report for purposes of clarity and to limit confusion. However, before reasonable success was achieved there were many experimental failures. Some of these will be described briefly as a caution to other potential investigators against pursuing certain routes.

For example, a number of experiments were tried in cracked ammonia and hydrogen atmosphere furnaces because it was believed that reducing atmospheres would be required to produce good wetting. These experiments invariably met with failure, the main problem being the formation of large voids in the band deposits. The rationale for this phenomenon was probably that large amounts of hydrogen were dissolved into the molten deposit which precipitated out as bubbles as the band solidified.

Another experimental failure of interest was an attempt to deposit an induction fused band of pure copper (99.83% Cu) under vacuum conditions of about 80 microns pressure. The problem that

Etch: Picral

Mag: 100 X

Figure 19. Unsoundness Near Interface of "Fused-On" Phosphor Bronze Band

occurred in these experiments was that so much gas evolved from the melt that molten copper was splashed around inside the vacuum container and even onto the container walls.

Another complete experimental failure was encountered in attempts to apply 8% aluminum bronze band deposits. With this composition, the shot simply would not flow together under the argon cover. Even the addition of an aluminum bronze braze welding flux did not correct the problem. The reason for these difficulties was probably the formation of an aluminum oxide skin on the outside of the shot. Such skins are not reducible even in hydrogen atmospheres.

Experiments that met with partial success and partial failure were conducted with copper (Alloy 189), graphite molds and braze welding flux in an air atmosphere. These experiments produced good quality deposits with induction heating but the main problem was that under these conditions the graphite mold reacted with the air and was eroded. In addition the flux tended to bond the deposit into the graphite mold making the projectile difficult to remove.

CONCLUSIONS

1. A new in-situ method for applying "fused on" rotating bands to projectiles has been demonstrated.

2. The new method can produce bands which are completely bonded to the projectile wall.

3. There is reason to believe that the new method can produce less wall damage to the projectile than the gas, metal arc, welded overlay process.

4. It has been demonstrated that at least several copper alloys can be applied.

5. It has also been demonstrated that copper alloy bands applied by the new method function successfully in firing tests.

RECOMMENDATIONS

It is recommended that additional study be given to this method to determine if the process can be refined to consistently produce high quality, high performance nonferrous bands. Further attention should be given to the furnace banding method because of the possibility of obtaining higher production rates. Less expensive atmospheres than argon should also perhaps be sought. Some of the copper casting alloys should be studied as rotating band materials since these might not only prove more suitable for some applications because of higher strengths but also may be particularly suited to the process.

If the method proves to be feasible as a production technique moderately large quantities of projectiles should be produced and test fired.